Distinguishing melt and fluids from graphite in the lower crust with multi-physics inversion

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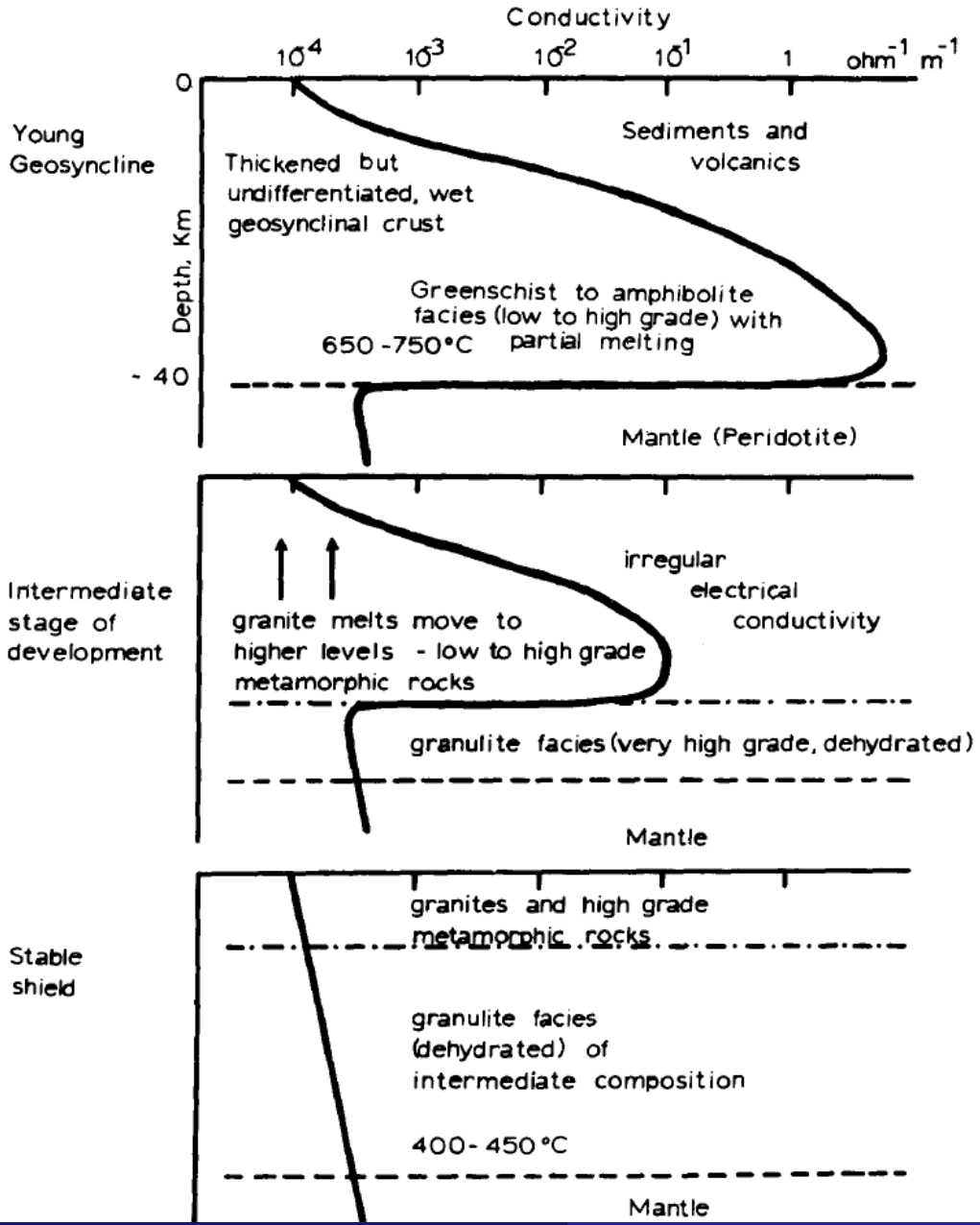
The beginnings



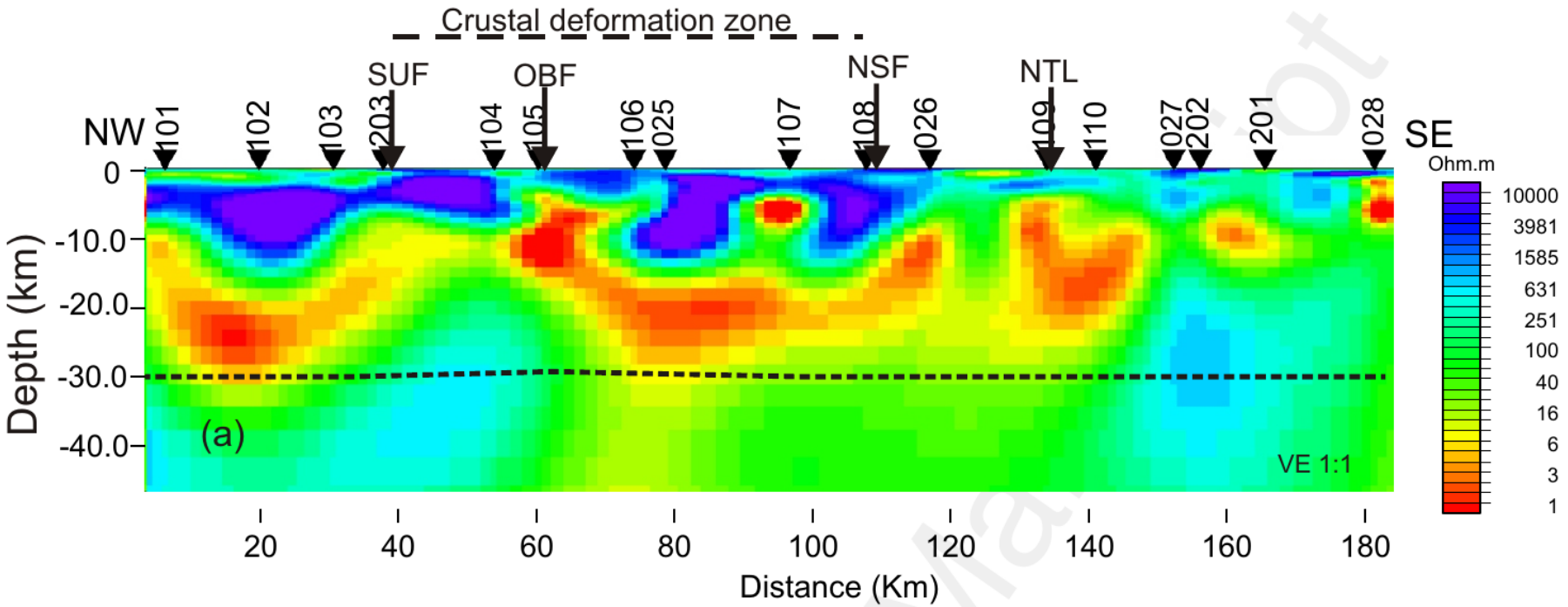
- Early EM studies (50s and 60s) inferred high conductivity in the continental crust in many areas
- First model by Hyndman and Hyndman (1968)
- Suggest fluids as a cause in "young" areas

Historical context

It might be added that the only deep anomaly which could explain the anomalous variations along the coast would consist of a step in the surface of the conductive core of enormous dimensions. On the oceanic side the depth of the core could not be greater than about 20km; on the continental side the depth of the core would range between 80 and 250 km depending on the period.

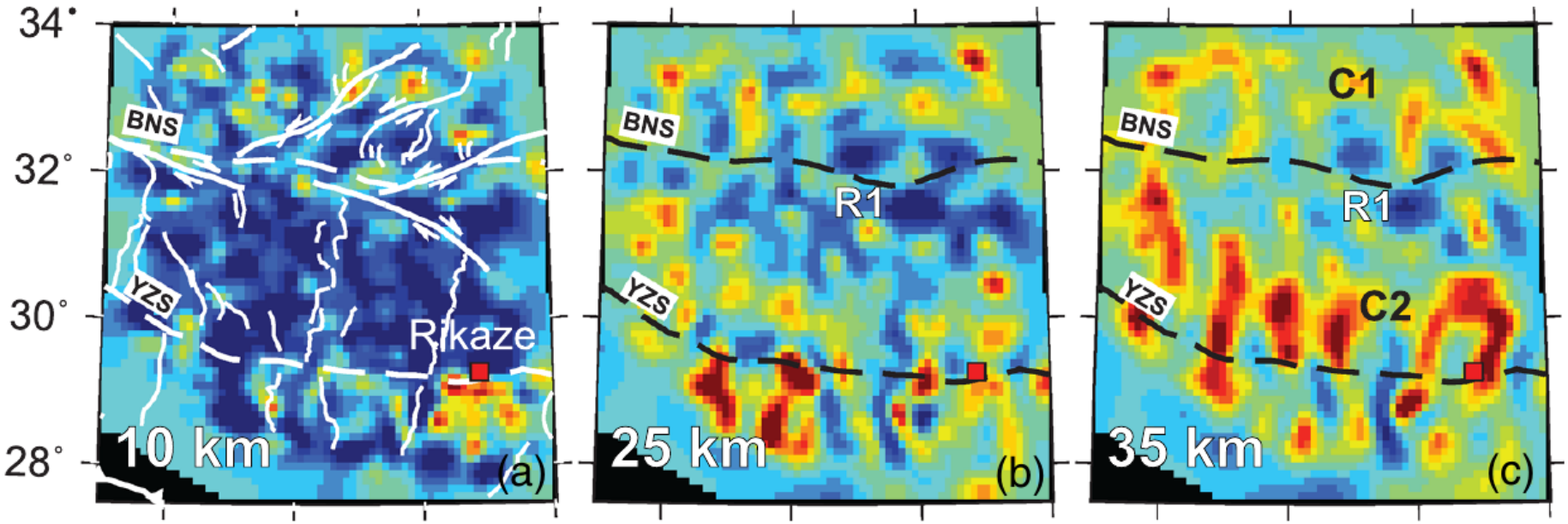
Schmucker, 1964

Ireland



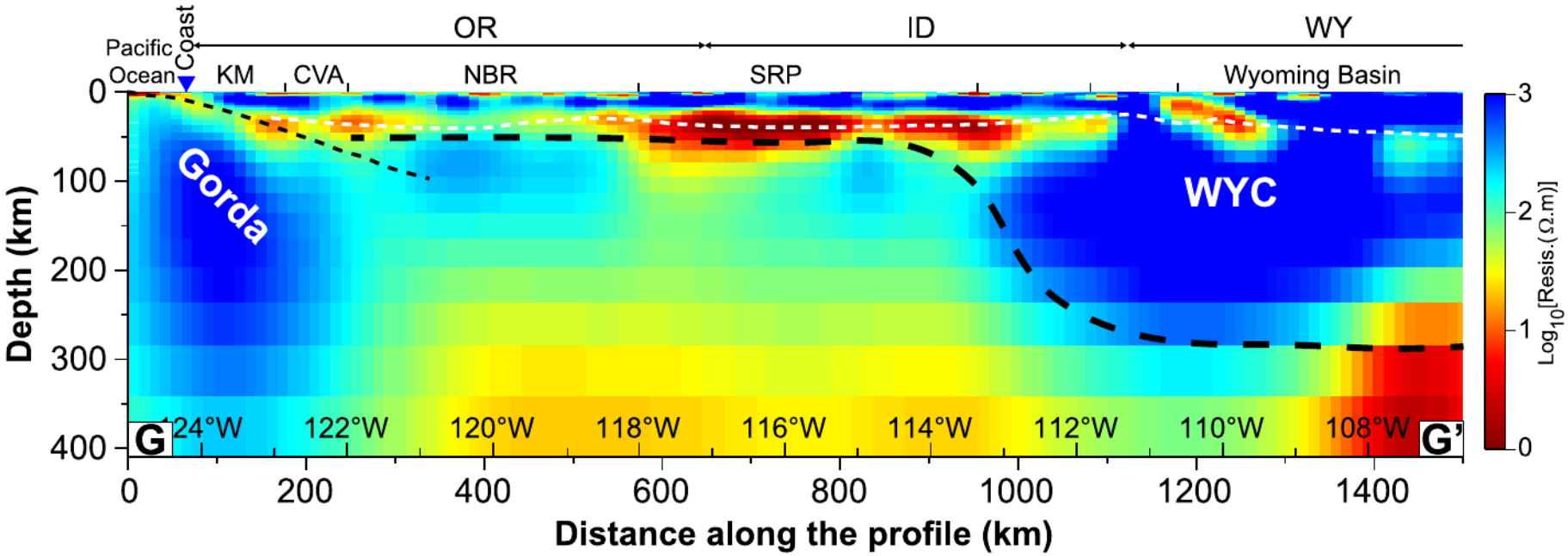
Graphite/Sulfide in metamorphosed Ordovician sediments
Rao et al., 2007

Tibet



Fluids/Melt associated with ongoing tectonic activity
Dong et al., 2020

Western United States



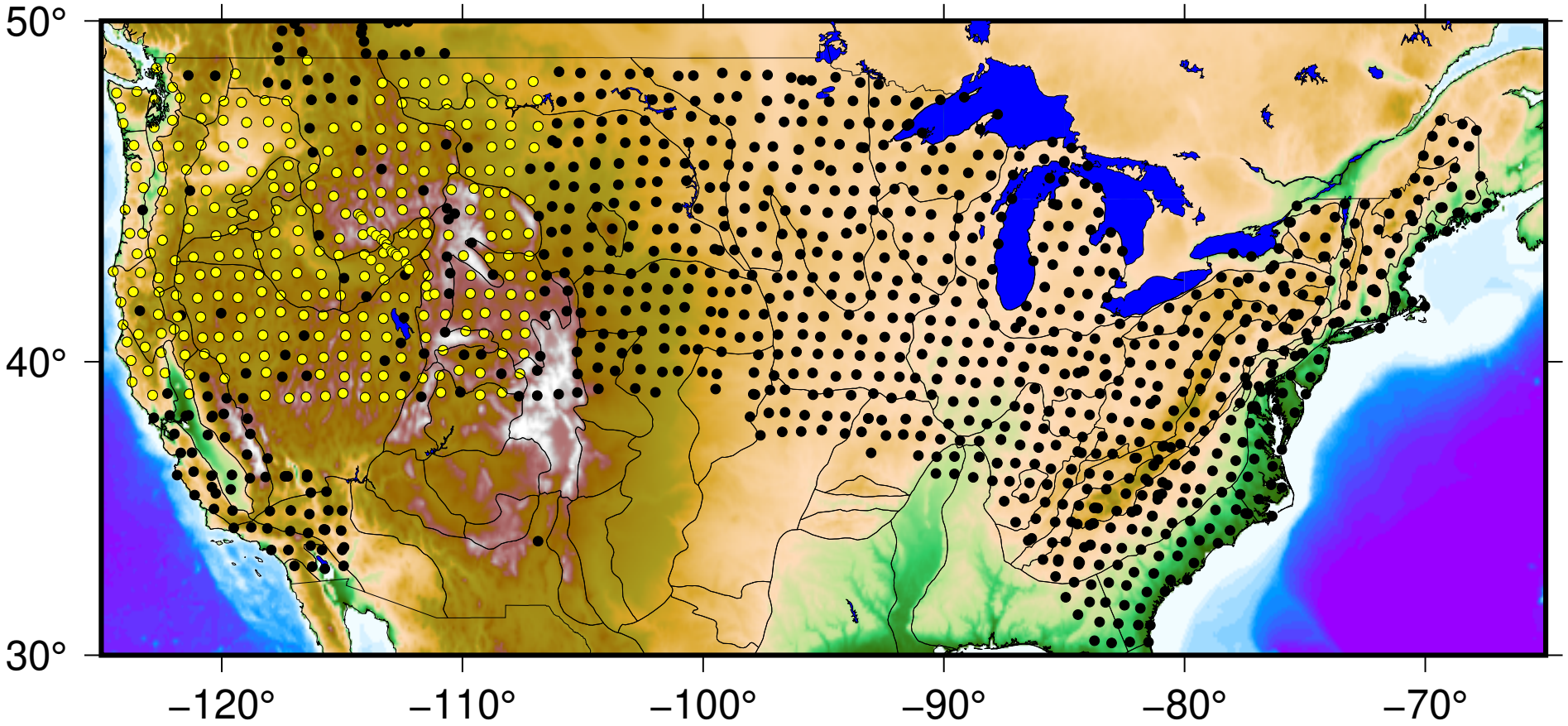
Fluids/Melt associated with ongoing tectonic activity
Meqbel et al., 2014

Modern explanations

Typically small amounts of connected conductive phase (1-10%) in resistive host rock

- Saline fluids, need to be retained, sometimes invoked in combination with melt (Tibet, Western US)
- Melt, needs high heat, active areas
- Graphite, remnant of past activity (fluids, deformation)
- Sulfides, less favored recently, thought to be not very abundant

USArray – Magnetotellurics



High quality MT measurements for lithospheric imaging across continental US.

Combine with satellite gravity data (XGM2016).

Joint inversion

- Combine different datasets to create consistent model and improve information content.
- Here Magnetotellurics (conductivity σ) and gravity (density ρ)

$$\Phi(\sigma,\rho) = \Phi_{MT}(\sigma) + \Phi_{grav}(\rho) + \Phi_{coupling}(\sigma,\rho)$$

- Minimize combination of data misfit terms $\Phi_{MT}(\sigma)$, $\Phi_{grav}(\rho)$ and coupling $\Phi_{coupling}(\sigma,\rho)$.
- Coupling crucial and defines expected connection.

Mutual information (MI)

- MI measures amount of information contained in variable X about variable Y (e.g. conductivity and density)
- Definition

$$I(X,Y) = H(X) + H(Y) - H(X,Y)$$

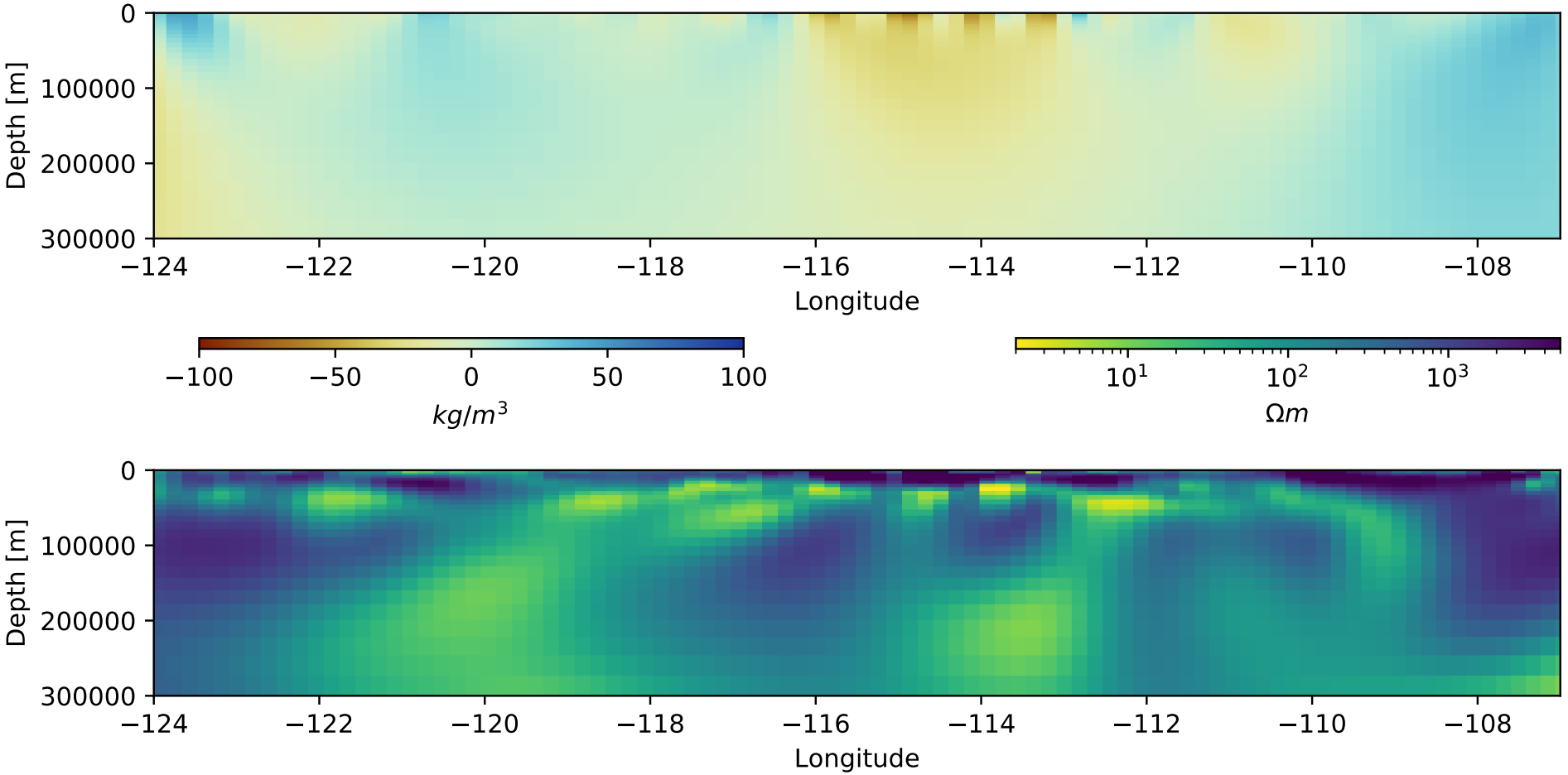
where

$$H(X) = -\sum_{i=1}^{N} P(x_i) \log P(x_i)$$

is the Shannon Entropy.

- Maximize mutual information as part of the inversion

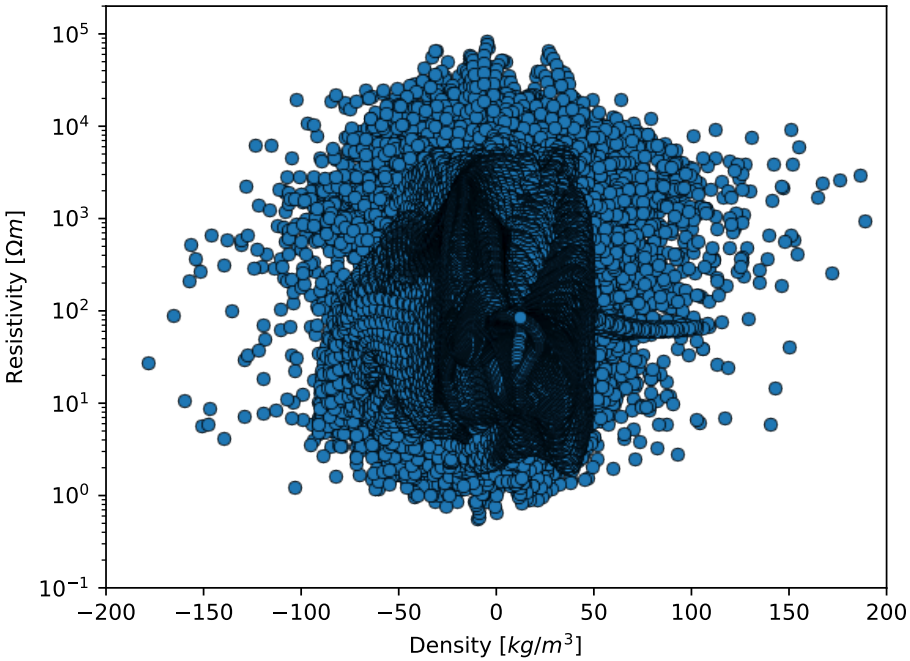
Mutual information – illustration



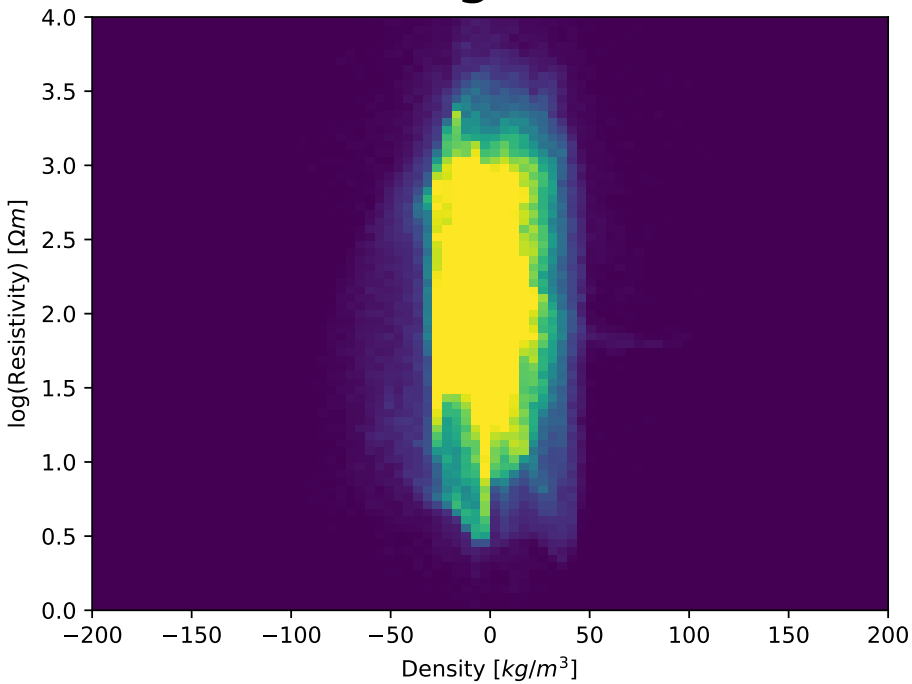
Individual models do not show similar features.

Mutual information – illustration

Parameter plot



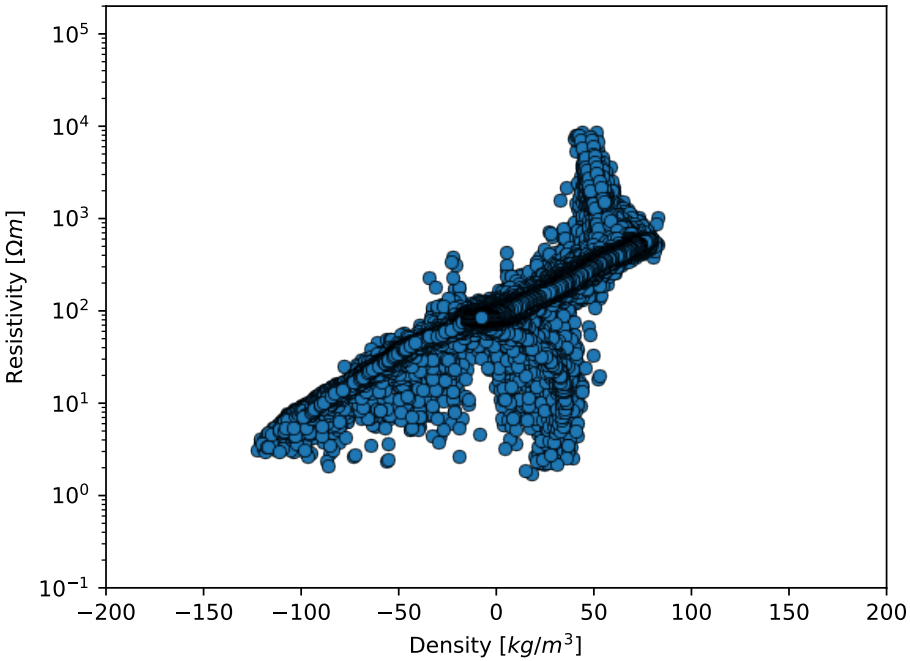
Histogram



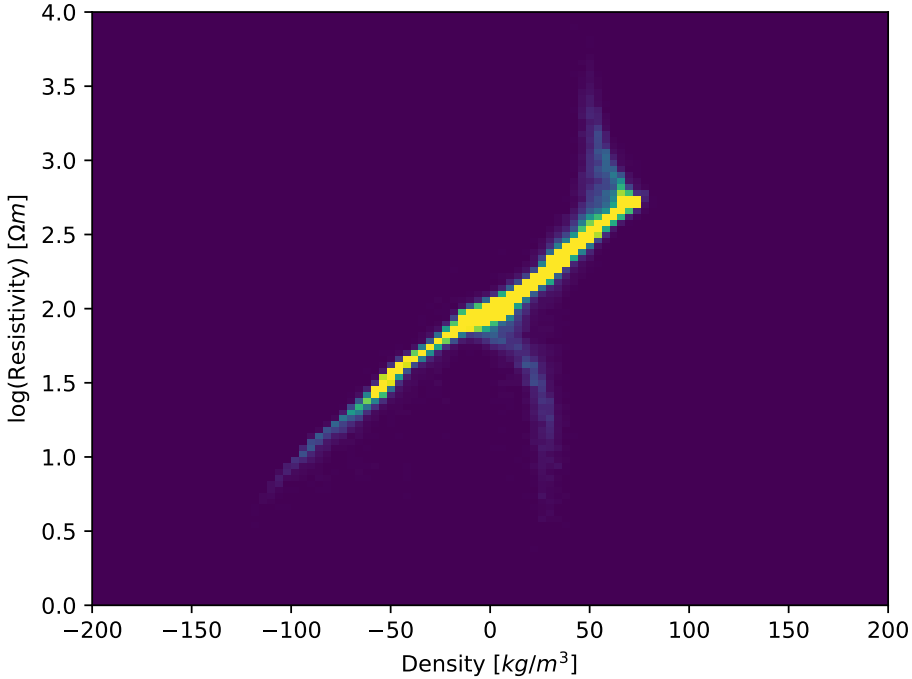
No relationship → low mutual information

Mutual information – illustration

Parameter plot

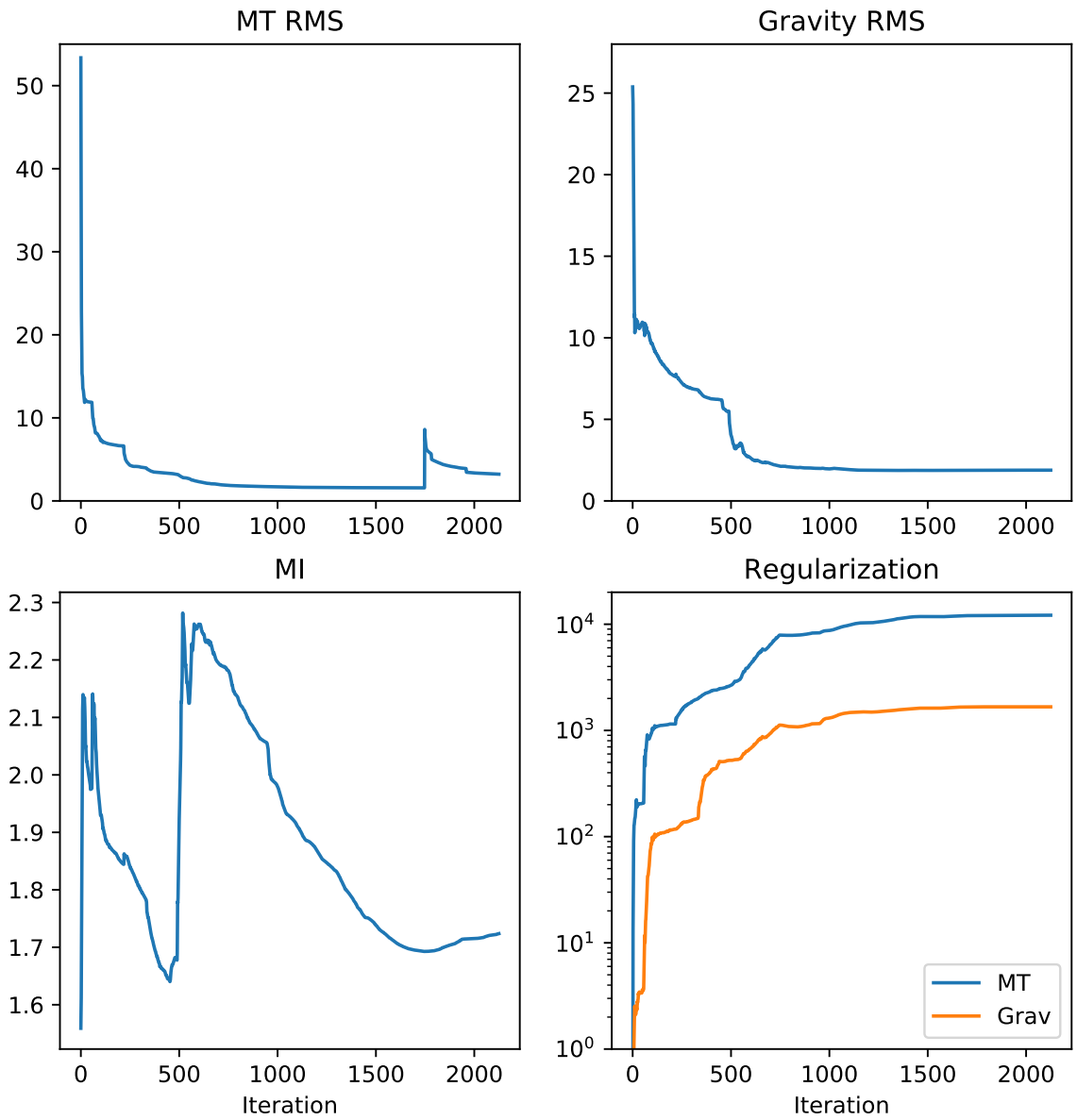


Histogram



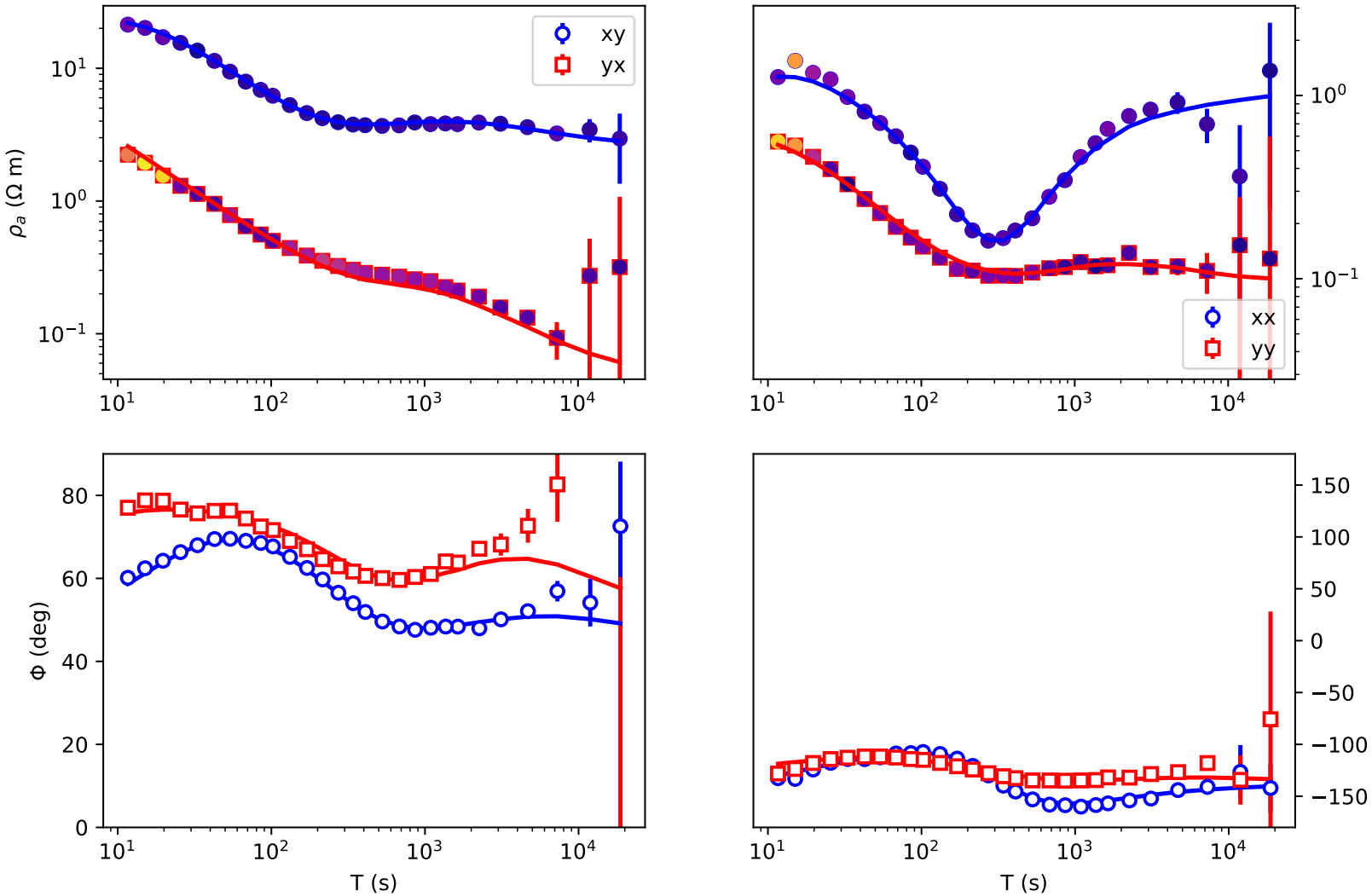
Noisy relationship → higher mutual information

Convergence

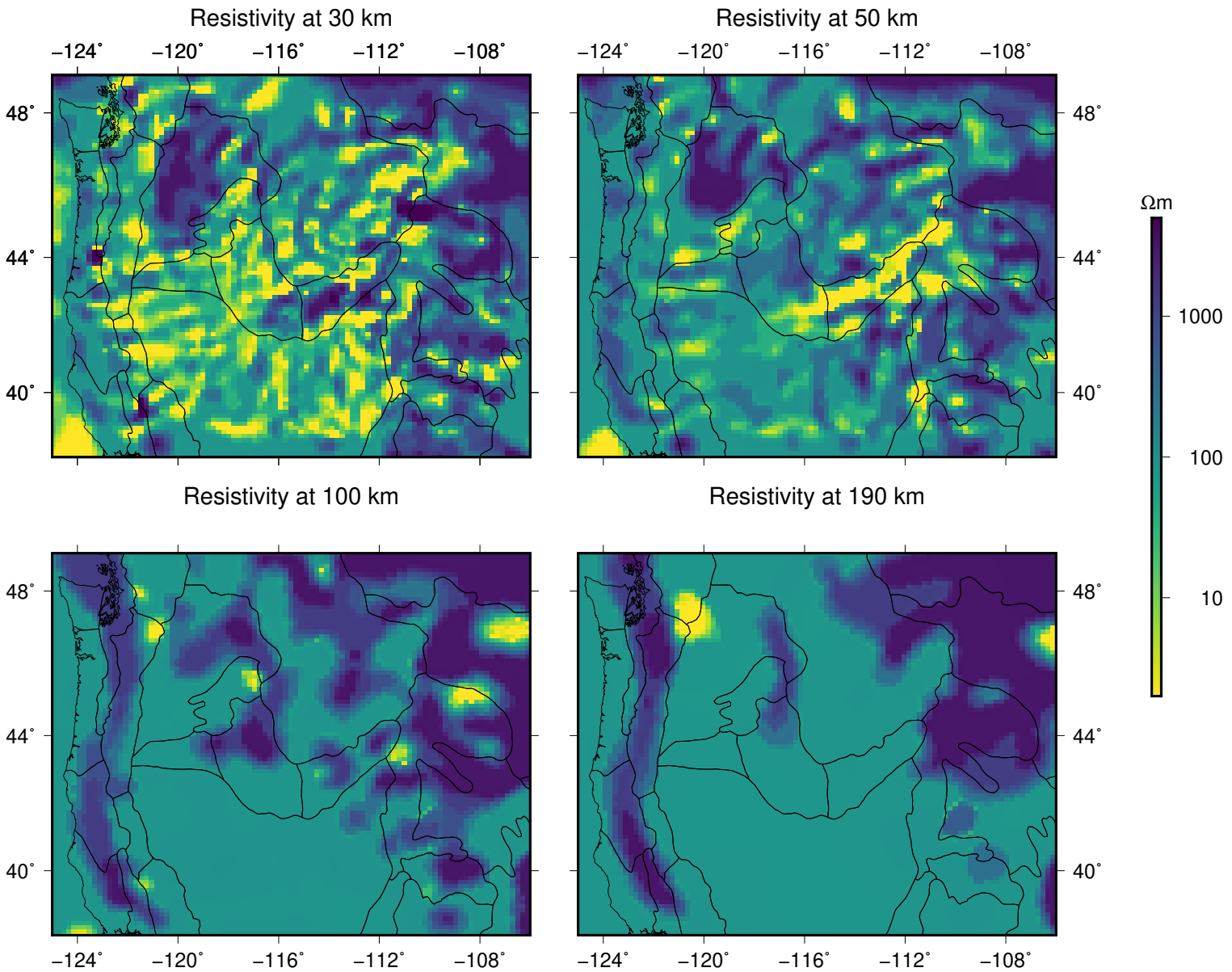


Data fit – MT

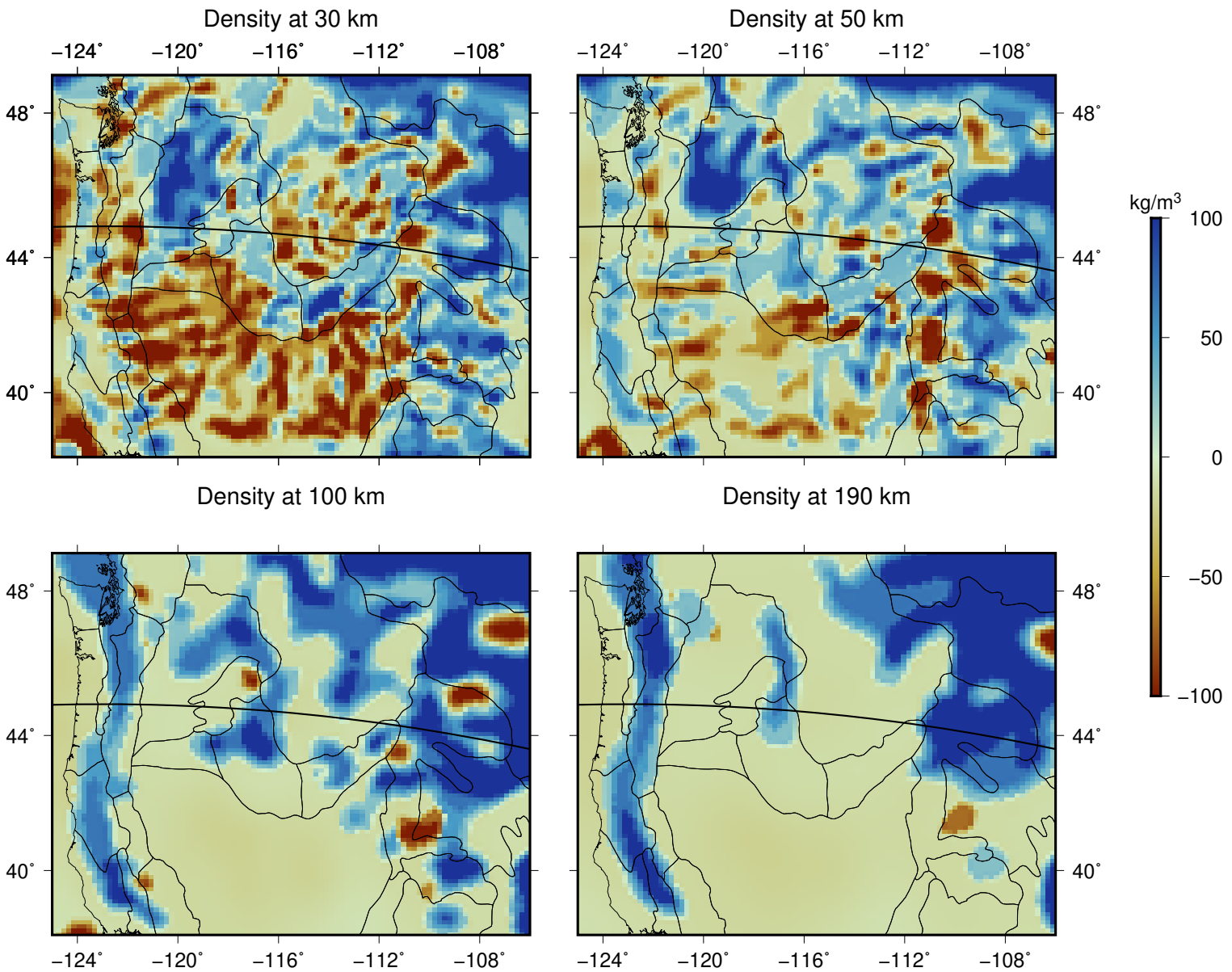
42: X 4978962.02479 Y 1259145.83622



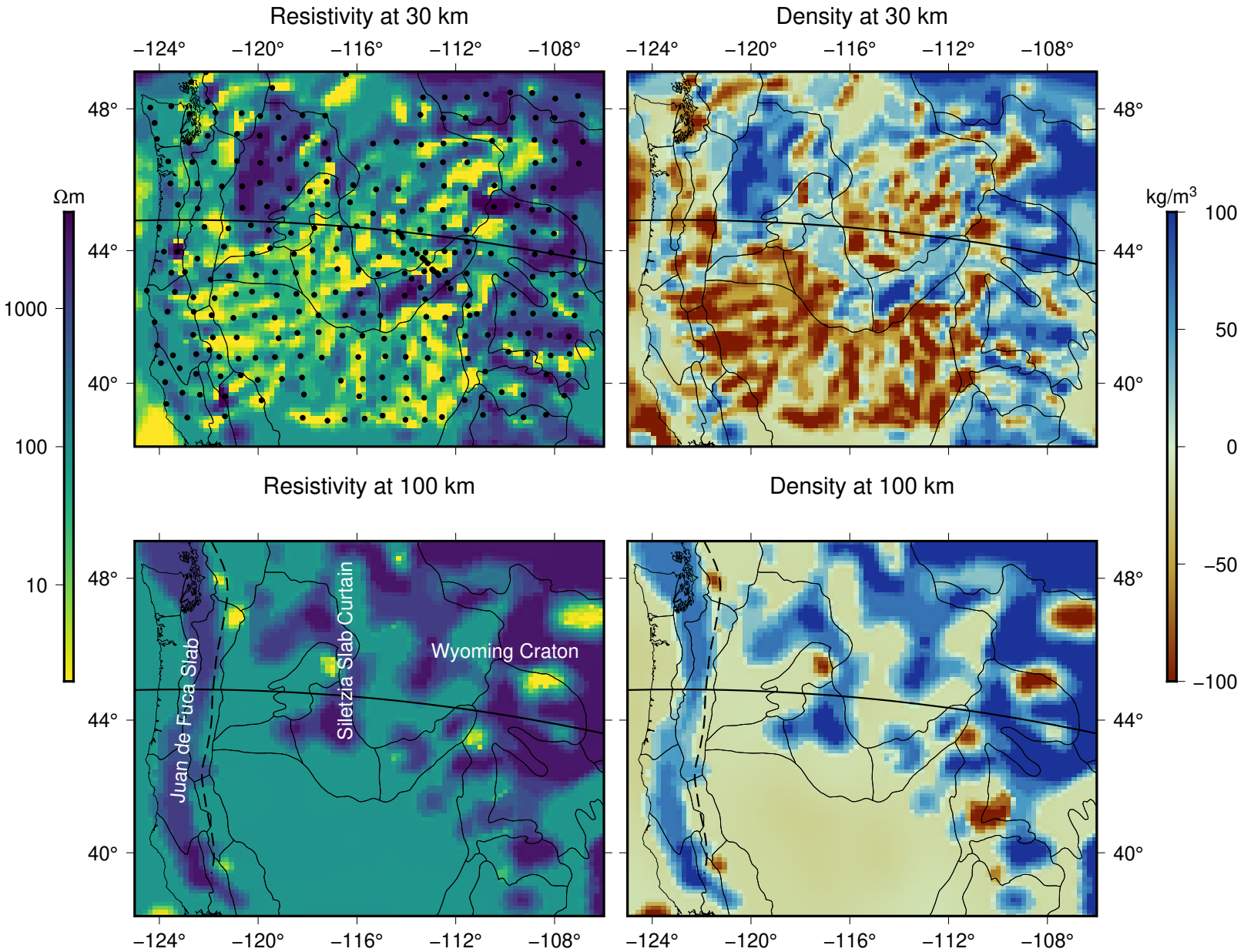
Joint inversion with MI – resistivity



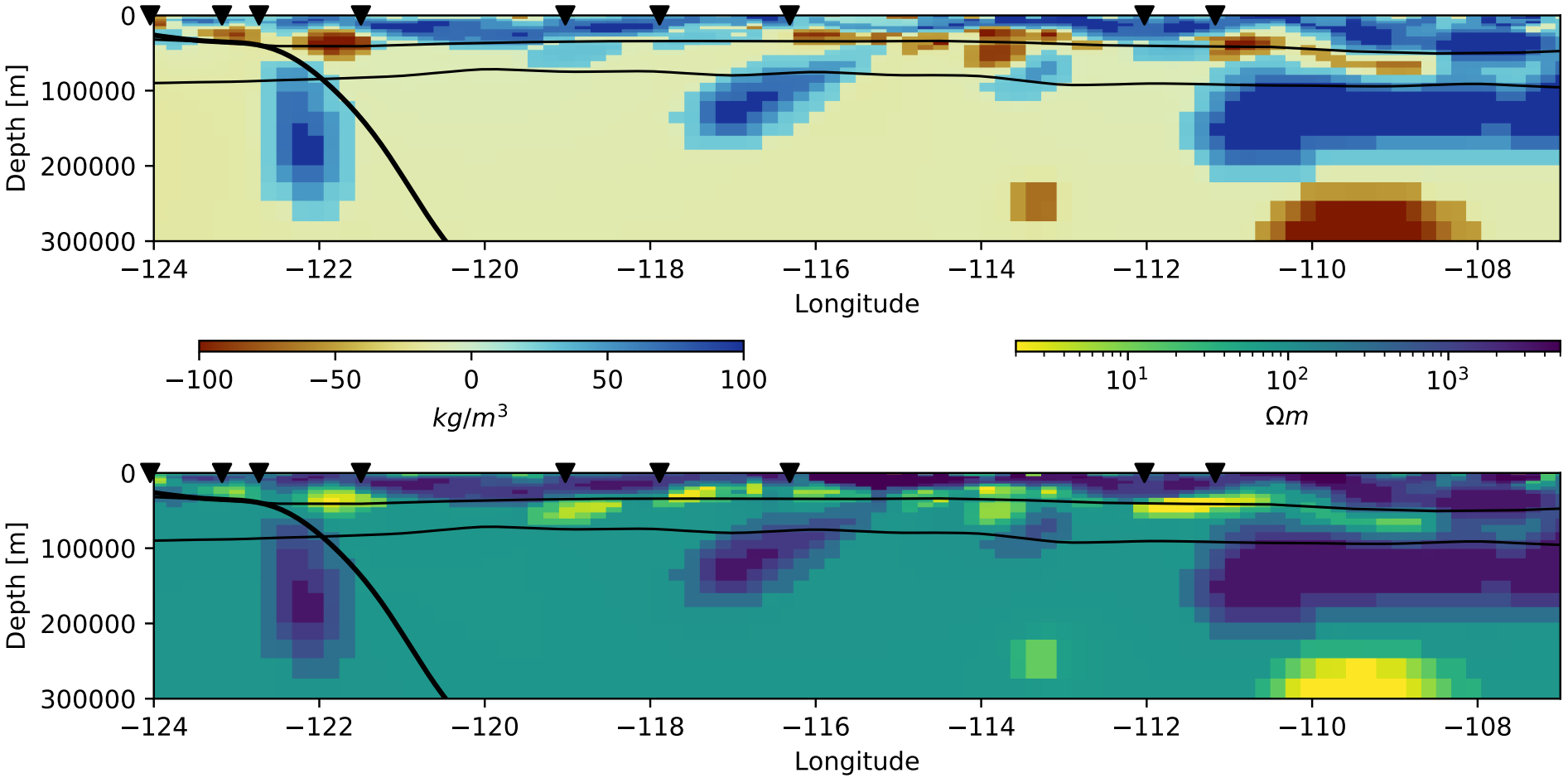
Joint inversion with MI– density



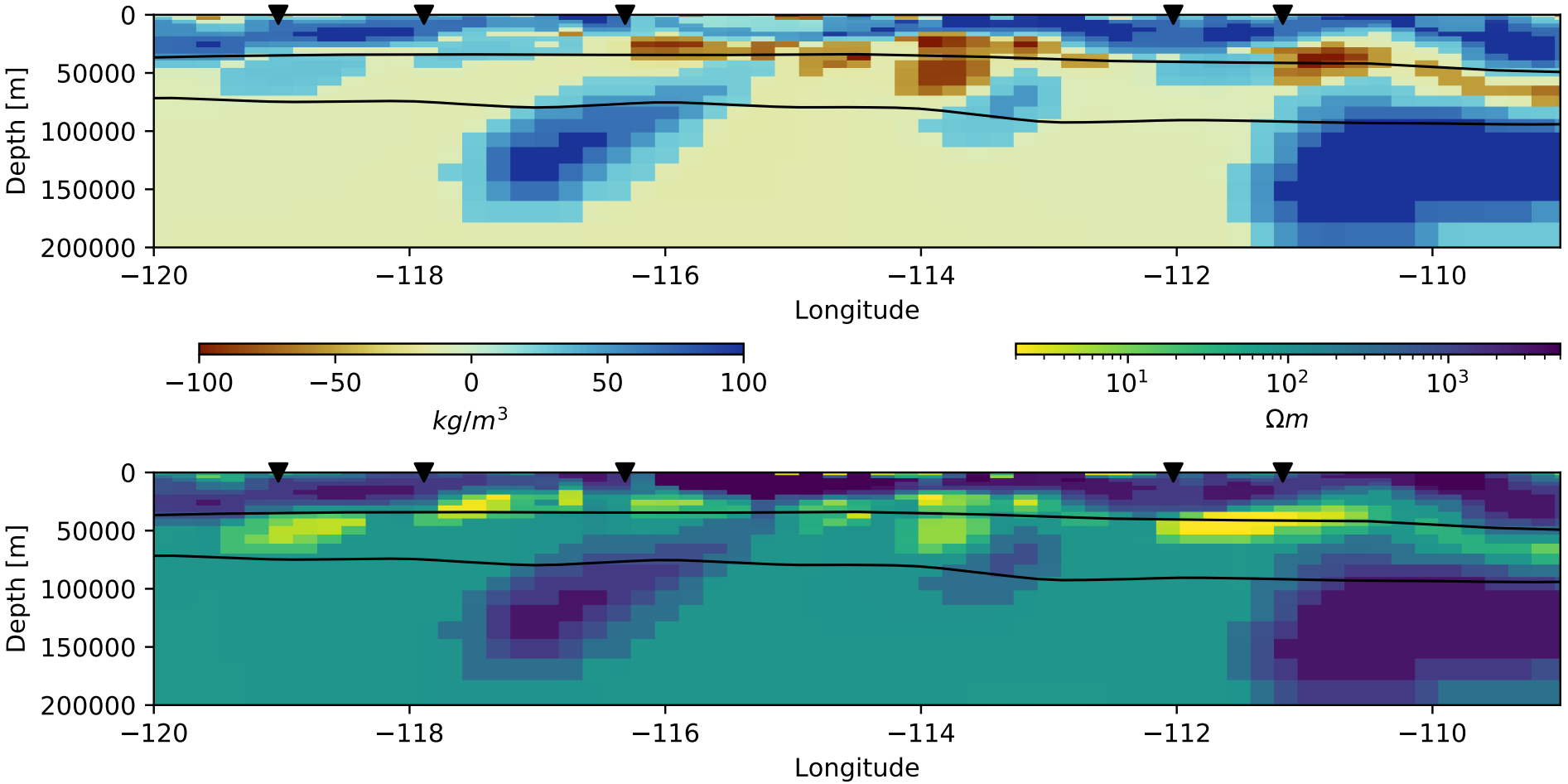
Joint inversion with MI



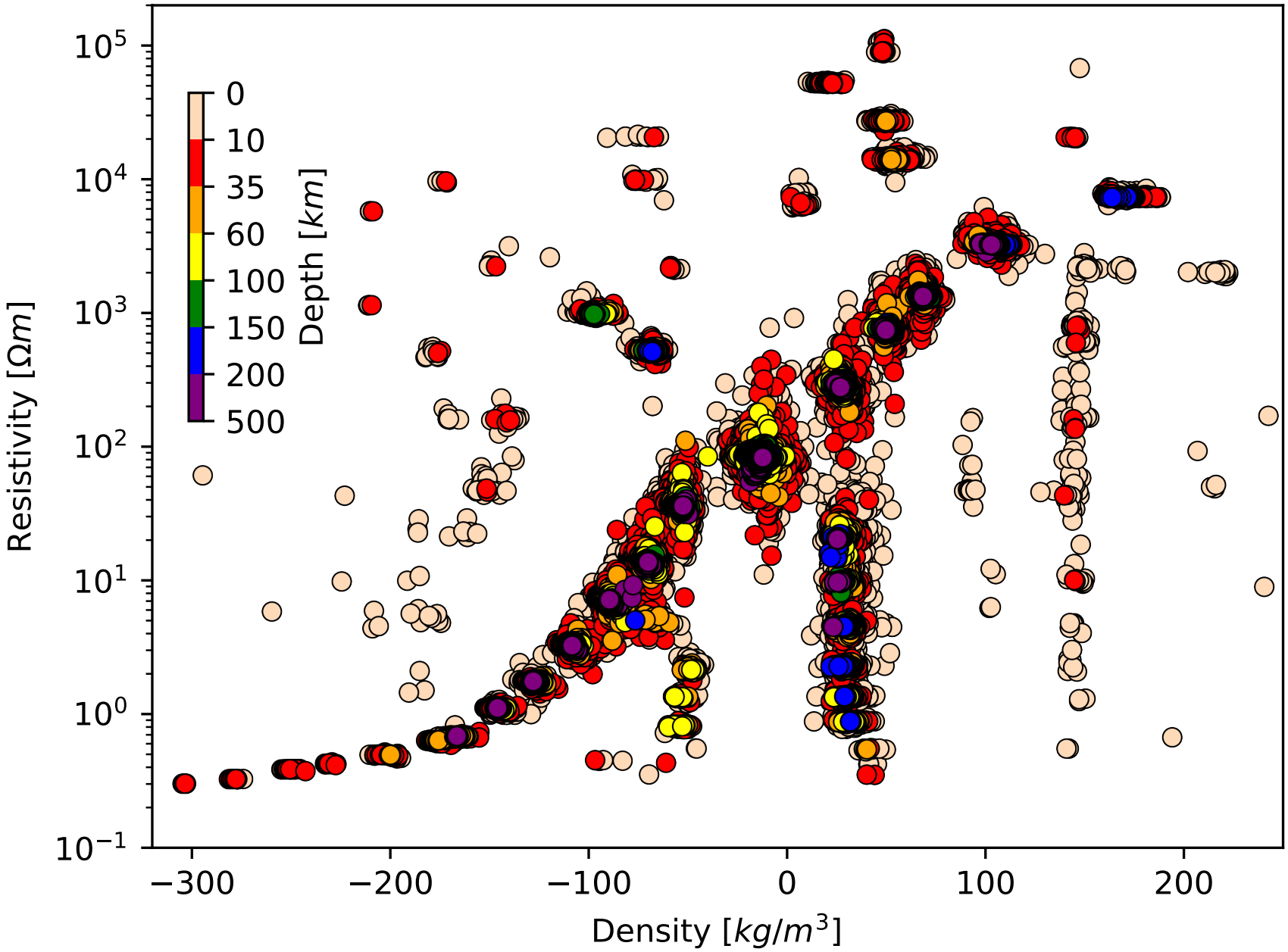
Joint inversion with MI – vertical profile



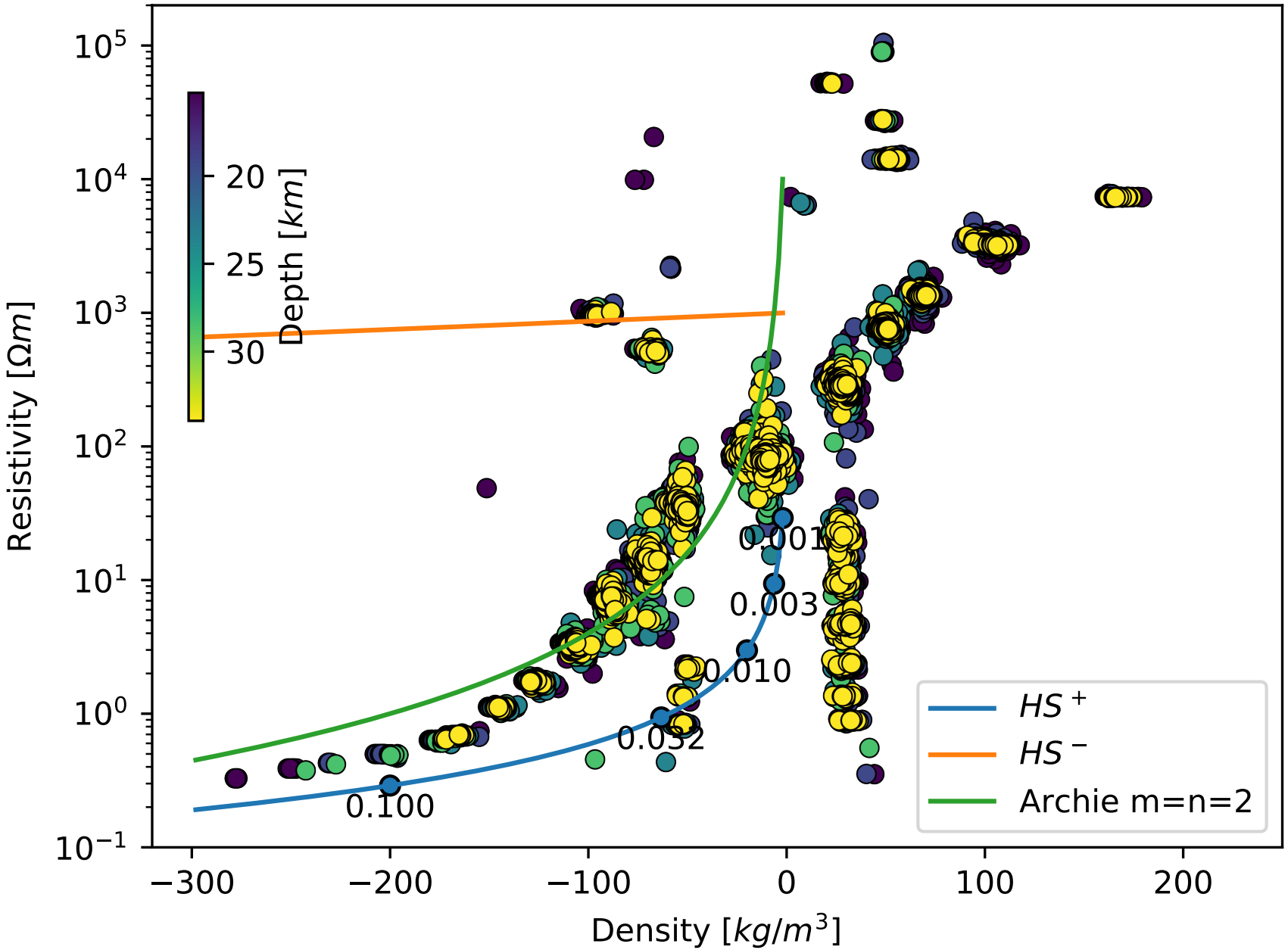
Joint inversion with MI – vertical profile



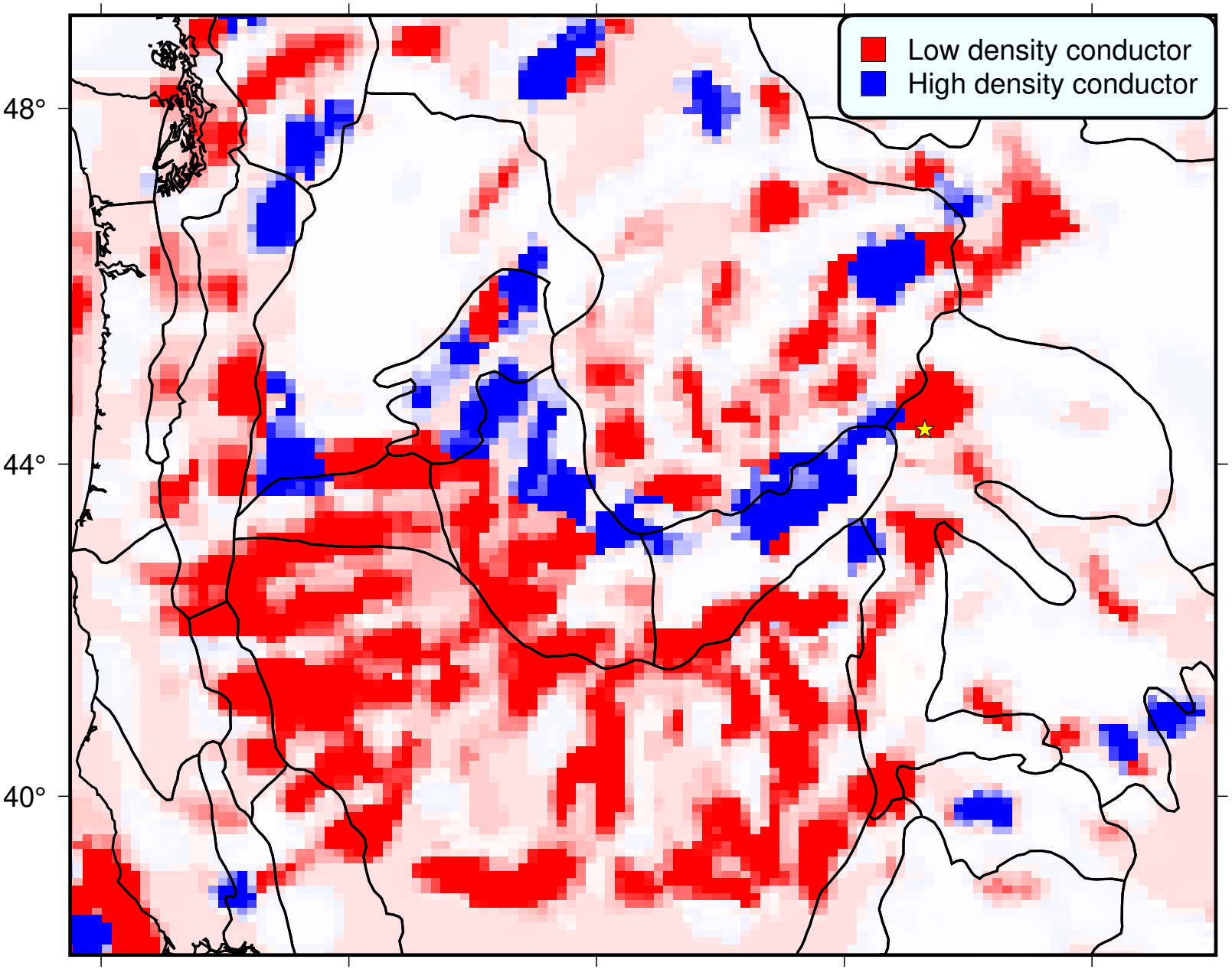
Parameter relationship –whole model



Parameter relationship –crust only



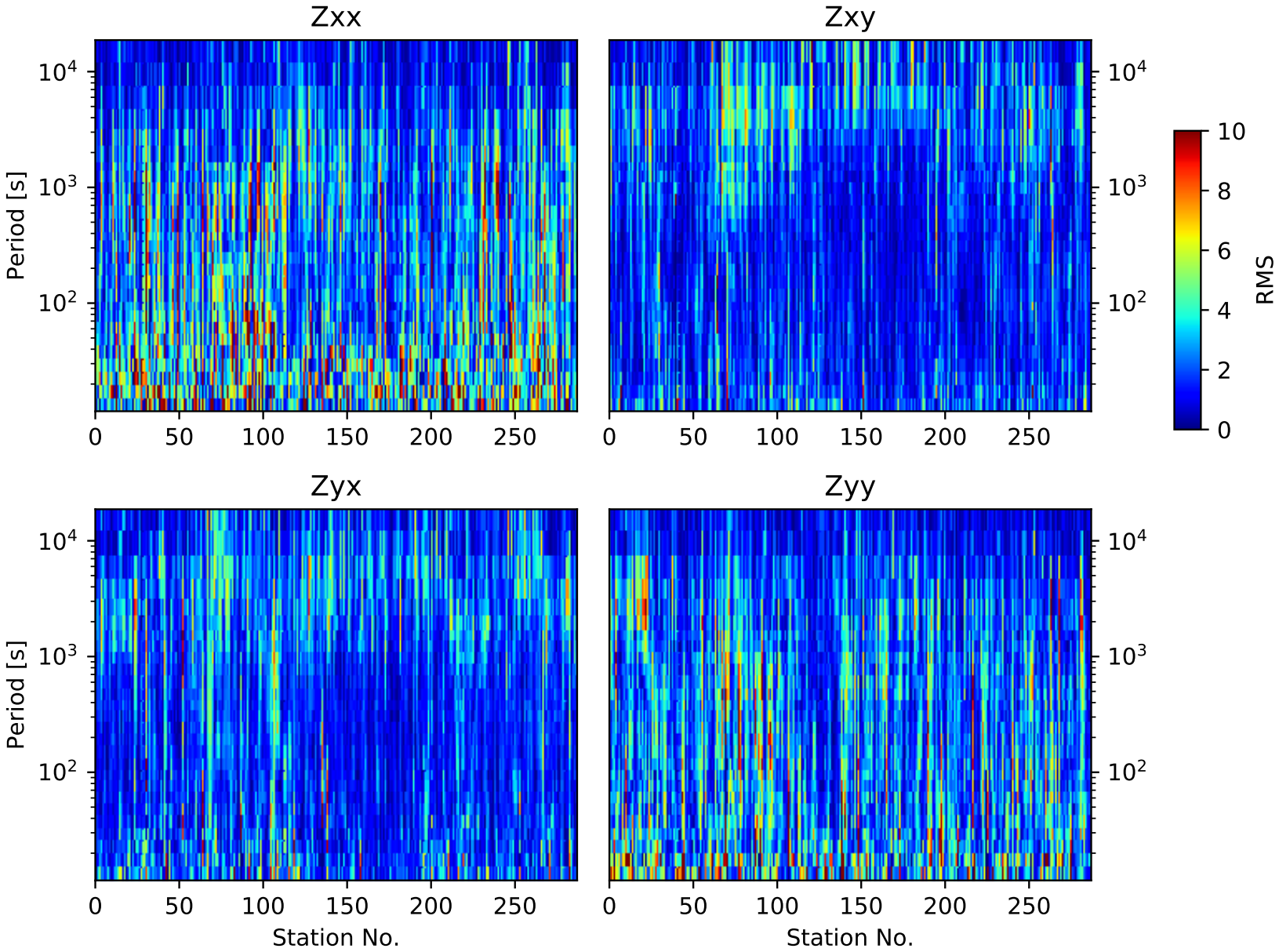
Crustal conductors



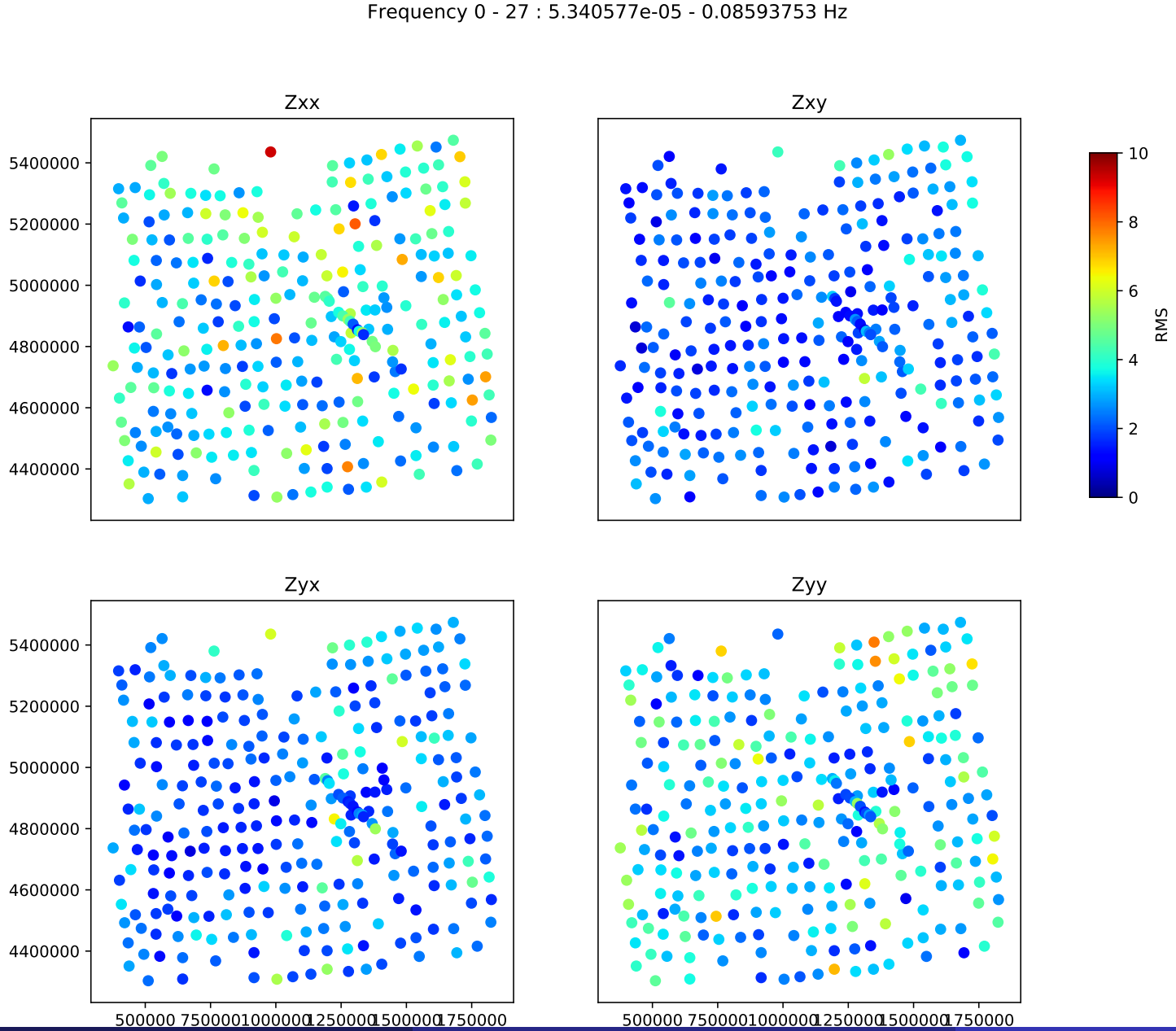
Conclusions

- Have developed new joint inversion with a mutual information coupling constraint
- Application to USArray data with MT and Gravity gives detailed models with many interesting features
- Retrieve well defined density-conductivity relationship, can be related to tectonic features
- Suggests current simple interpretation approaches of crustal conductivity are not tenable

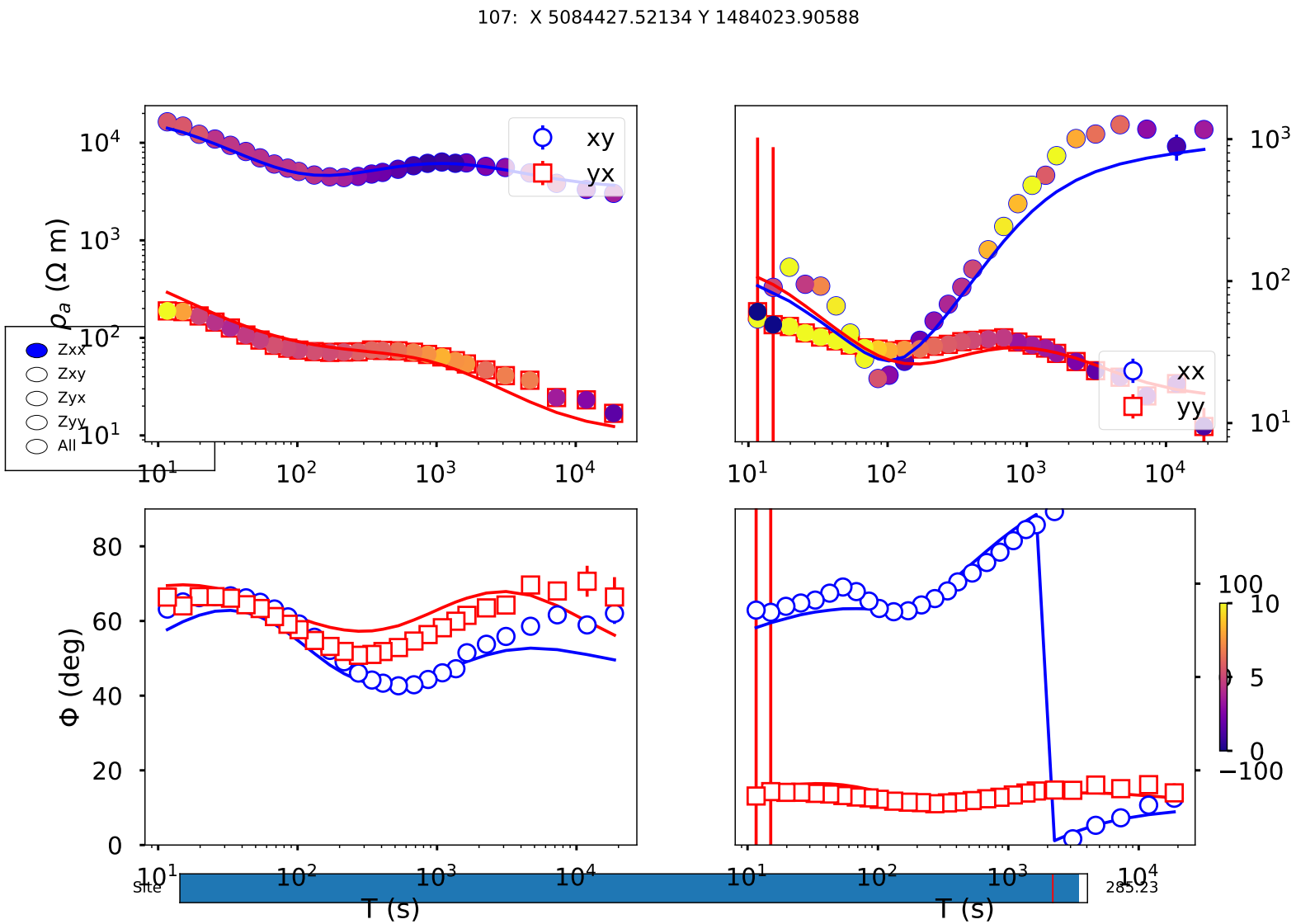
MT misfit section



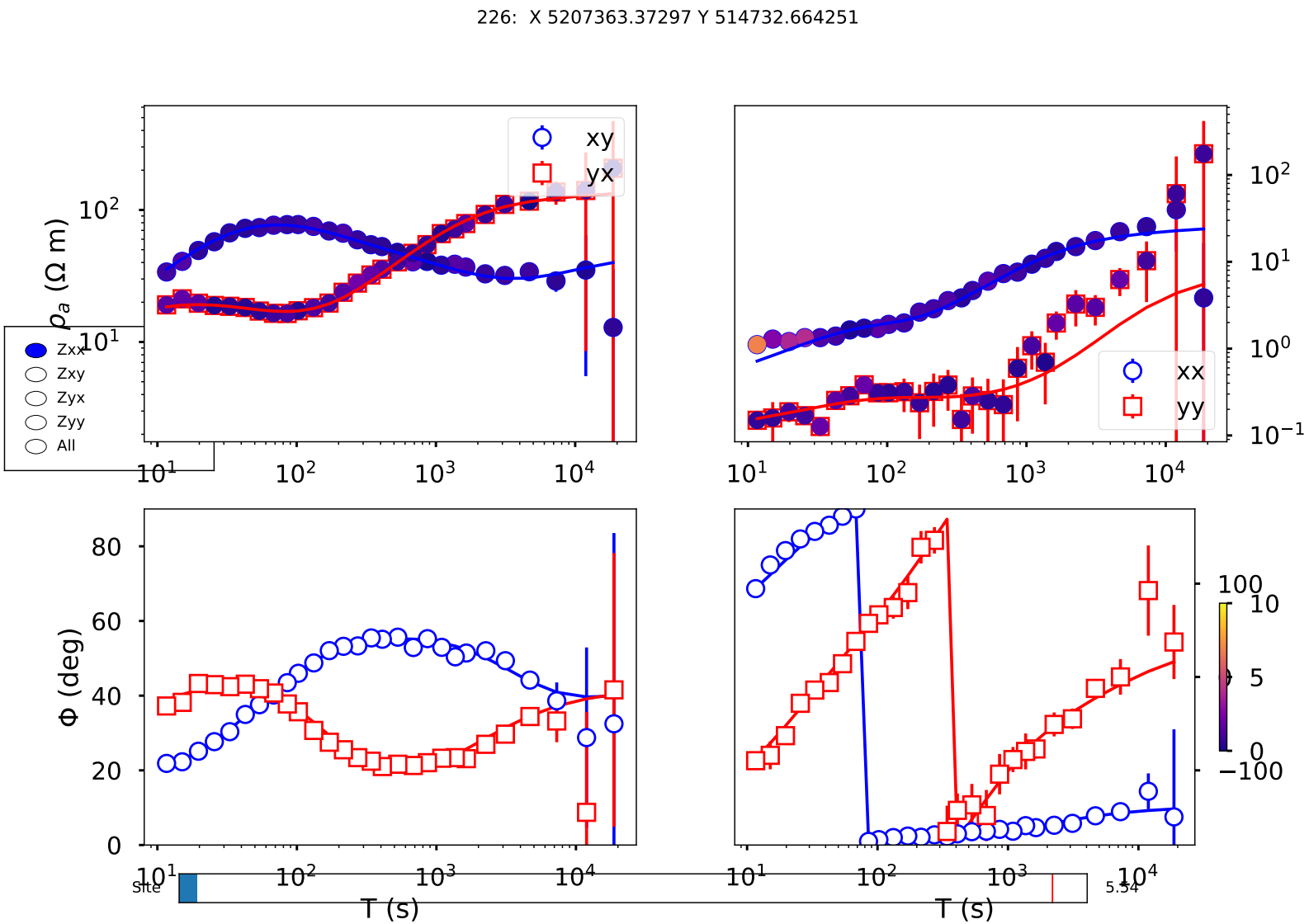
MT misfit map



MT worst fit


107: X 5084427.52134 Y 1484023.90588
xy
yx
xx
yy
Zxx
Zxy
Zyx
Zyy
All
ρ_a (Ω m)
Φ (deg)
T (s)
T (s)
Site
285.23

MT best fit


226: X 5207363.37297 Y 514732.664251
xy
yx
xx
yy
Zxx
Zxy
Zyx
Zyy
All
ρ_a (Ω m)
Φ (deg)
T (s)
T (s)
Site
5.54

MT misfitsection